Perioperative thermal insulation: minimal clinically important differences?

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Background. Reduction of heat losses from the skin by thermal insulation is used to avoid perioperative hypothermia. However, there is little information about the physical properties of various insulating materials used in the operating room.

Methods. The following insulation materials were tested using a validated manikin: cotton surgical drape tested in two and four layers; Allegiance drape; 3M Steri-Drape; metallized plastic sheet; Thermadrape™; Barkey thermcare 1 tested in one and two layers; hospital duvet tested in one and two layers. Heat loss from the surface of the manikin can be described as:

\[
Q = h \Delta T A
\]

where \(Q\) is heat flux, \(h\) is the heat exchange coefficient, \(\Delta T\) is the temperature gradient between the environment and surface and \(A\) is the area covered. The heat flux per unit area (\(QA^{-1}\)) and surface temperature were measured with nine calibrated heat-flux transducers. The environmental temperature was measured using a thermoanemometer. \(\Delta T\) was varied and \(h\) was determined by linear regression analysis as the slope of \(\Delta T\) vs \(QA^{-1}\). The reciprocal of \(h\) defines the insulation.

Results. The insulation value of air was 0.61 Clo. The insulation values of the materials varied between 0.17 Clo (two layers of cotton surgical drapes) to 2.79 Clo (two layers of hospital duvet).

Conclusions. There are relevant differences between various insulating materials. The best commercially available material designed for use in the operating room (Barkey thermcare 1) can reduce heat loss from the covered area by 45% when used in two layers. Given the range of insulating materials available for outdoor activities, significant improvement in insulation of patients in the operating room is both possible and desirable.

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reduce heat loss from the skin, there is little information about the physical properties of various insulating materials used in the operating room. Therefore the following study compared the efficacy of seven insulating materials using a validated copper manikin to simulate the human body.

Methods

Heat exchange between a dry surface and the environment is caused by radiation and convection. This heat exchange process can be described as:

\[ Q = h \cdot \Delta T \cdot A \]

where \( Q \) is heat flux (W), \( h \) is the heat exchange coefficient (W m\(^{-2}\) °C\(^{-1}\)), \( \Delta T \) is the temperature gradient between the environment and surface (°C) and \( A \) is the area covered (m\(^2\)).

\( Q \) per unit area (\( QA^{-1} \)) can be measured directly with heat-flux transducers, and temperatures can be measured with standard thermometric techniques. From these data, \( h \), which defines the efficiency of heat exchange, can be calculated. Covering a surface with insulation decreases heat flow to the environment, therefore lowering \( h \). The reciprocal of \( h \) defines the resistance to heat exchange, or the insulation. Insulation values can be expressed in SI units (°C m\(^{-2}\) W\(^{-1}\)), °C m\(^{-2}\) W\(^{-1}\) or Clo units. One Clo unit is equivalent to the insulation required to keep a seated subject comfortable at an air temperature of 21°C in an air movement of 0.1 m s\(^{-1}\). Such insulation is provided by an ordinary suit, with shirt, trousers etc.16 One Clo is equivalent to 0.155°C m\(^{-2}\) W\(^{-1}\).

The following insulation materials were tested: (i) cotton surgical drape TB 202 B (160 cm × 140 cm) (Karl Dieckhoff GmbH & Co. KG, Wuppertal, Germany), tested in two and four layers, because surgical cotton drapes are rarely used in one layer; (ii) Allegiance beach chair shoulder drape (262 cm × 411 cm) (Allegiance Healthcare Corporation, McGaw Park, IL, USA); (iii) 3M Steri-Drape adhesive split sheet No. 9045 (228 cm × 260 cm) (3M Health Care, St Paul, MN, USA); (iv) metallized plastic sheet (140 cm × 220 cm) (VauDe, Norderstedt, Germany), tested with the silver side facing the manikin; (v) Thermadrape\(^{TM}\) Blanket T2000 (120 cm × 120 cm) (OR Concepts, Roanoke, TX, USA); (vi) Barkey thermcare I whole body blanket for adults (220 cm × 140 cm) (Barkey GmbH & Co. KG, Leopoldshöhe, Germany) which consists of cotton, polyester and polyester with polyurethane coating; it was tested in one and two layers; (vii) hospital duvet (188 cm × 122 cm) (Brinkhaus GmbH & Co. KG, Warendorf, Germany), filled with Trevira (100% polyester). The hospital duvet was tested together with its covering (140 cm × 200 cm) (Karl Dieckhoff GmbH & Co. KG, Wuppertal, Germany) made of 50% polyester and 50% cotton and was tested as one and two duvets (one and two layers).

The manikin

The manikin consists of six copper tubes painted matt black. Two tubes serve as arms, two as legs, one as the head and one as the trunk. The total surface area of all tubes is 1.98 m\(^2\). In order to set surface temperature and achieve steady-state conditions, water mattresses (Maxi-Therm®, Cincinnati Sub-Zero Products Inc., Cincinnati, OH, USA) are bonded to the inner surface of the copper tubes. The circulating water is warmed and cooled by a hyperthermia system (Hico-Variotherm 530, Hirtz & Co. Hospitalwerk, Cologne, Germany).

Measurement of environmental conditions

Air humidity and velocity were measured using a gauged thermoanemometer (VelociCalc plus TSI\(^{TM}\) Model 8388-M-D, TSI Incorporated, St Paul, MN, USA).

Measurement of heat exchange at the manikin

We measured \( QA^{-1} \) between the environment and the manikin with nine calibrated heat-flux transducers (Heat Flow Sensor Model FR-025-TH44033-F16, Concept Engineering, Old Saybrook, CT, USA) distributed equally over the trunk of the manikin.

Measurement of temperature gradient

The temperature gradient was defined as the difference between the environmental temperature and the surface temperature of the manikin underneath the heat-flux transducer. The environmental temperature was measured in the middle of the room and near the wall using the thermoanemometer. The surface temperature of the manikin was measured with calibrated thermistors incorporated into the heat-flux transducers.

Data sampling

Heat-flux signals were measured and digitized using a Dash TC AD converter (Keithley Instruments Inc., Taunton, MA, USA). The thermistors incorporated into the heat-flux transducers for measurement of the manikin surface temperature were connected to Hellige Servomed 236039 monitors (Hellige, Freiburg, Germany). The signal of these monitors was digitized on a Dash 1402 A/D board (Keithley Instruments Inc., Taunton, MA, USA). All data were sampled synchronously in 10 s intervals on a computer, averaged over 1 min and written to a hard disk.

Determination of the heat exchange coefficient

The trunk of the manikin was completely covered with the insulation material, which was smoothed flat to exclude any obvious trapped air. To determine \( h \), \( QA^{-1} \) and \( \Delta T \) were measured simultaneously over a range of temperature...
differences. Six tests were created by setting six different surface temperatures of the manikin (22, 26, 30, 34, 38 and 42 °C). Each test consisted of a 60 min preparation period to achieve steady-state conditions followed by a 20 min measurement period. The collected data were averaged for the single measurement period. Each test was repeated three times. There were nine sites, six tests and three repetitions, so that \( h \) was calculated from 162 results for \( Q_{A}^{-1} \) and the corresponding temperature gradients. \( h \) was calculated by linear regression analysis as the slope of \( Q_{A}^{-1} \) as a function of the temperature gradient. Heat flux from the manikin to the environment was called heat loss and was assigned a negative value.

**Calculation of the insulation values of the tested materials**

The insulation of the trunk of the manikin when covered with an insulation material represents the total insulation provided by the insulation material and the insulation of air. Therefore the insulation of air was determined by exposing the manikin, using only air as the insulating material. Subtracting the insulation of air from the total insulation gave the insulation value of the tested material.

**Results**

The mean ambient temperature for all trials was 22.6 (SD 0.3)°C, the relative humidity was 40.5 (6.3)% and the air velocity was below 0.2 m s\(^{-1}\) with no relevant difference between the single measurement series.

**Insulation value of air**

\( h \) for the trunk of the manikin was 10.6 W m\(^{-2}\) °C\(^{-1}\) (Fig. 1) The reciprocal of \( h \) defines the resistance to heat exchange, or the insulation. This resistance is \( 1/h = 1/10.6 \) W m\(^{-2}\) °C\(^{-1} = 0.09 \) °C m\(^{-2}\) W\(^{-1}\) or 0.9 tog or 0.61 Clo.

**Insulation value of the materials**

Values of \( h \) for the trunk of the manikin and the insulation materials varied between 8.3 and 1.9 W m\(^{-2}\) °C\(^{-1}\). This corresponds to total insulation values of 0.12–0.53°C m\(^{-2}\) W\(^{-1}\) or 1.2–5.3 tog or 0.78–3.40 Clo for the material and air together. Subtracting the insulation of air gave insulation values for the materials of 0.3–4.4 tog or 0.17–2.79 Clo (Table 1, Fig. 2).

**Discussion**

Thermal insulation reduces heat loss from the surface of the manikin to the environment by decreasing the radiative and convective heat exchange. This decrease in heat loss is shown by an equivalent decrease in \( h \), provided that the same temperature gradient exists. When total insulation is expressed in SI units, \( h \) is inversely related to total insulation since insulation is \( 1/h \). When total insulation is expressed in Clo units, then \( h = 6.45/x \), since 1 Clo = 0.155°C m\(^{-2}\) W\(^{-1}\) and \( 1/0.155 = 6.45 \) (Fig. 2). This relationship implies that adding a little insulation to an uninsulated surface can decrease heat loss in a relevant way (e.g. insulating an exposed surface with 0.17 Clo reduces heat loss by 28%) but adding more insulation to an already well insulated surface will have only a small effect on heat loss (e.g. increasing insulation from 2.6 to 2.8 Clo will only decrease \( h \) from 2.48 to 2.30 W m\(^{-2}\) °C\(^{-1}\), a reduction in heat loss of only 9%).

**Different types of thermal insulators**

Thermal insulators can be divided into two different types. The majority consist of mass insulators (cotton surgical

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**Fig 1** Determination of the heat exchange coefficient (\( h \)) of air. The slope of the temperature (T) gradient between the environment and the surface of the manikin vs the measured heat flux per area (\( Q_{A}^{-1} \)). The data show the regression line and 95% confidence intervals.

**Table 1** Heat exchange coefficient (\( h \)) of the heat exchange between the manikin and the environment, corresponding total insulation (insulation of the material and air) and insulation of the material

<table>
<thead>
<tr>
<th>Insulation material</th>
<th>( h ) (W m(^{-2}) °C(^{-1}))</th>
<th>Total insulation (Clo)</th>
<th>Insulation of the material (Clo)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air</td>
<td>10.6</td>
<td>0.61</td>
<td>0.17</td>
</tr>
<tr>
<td>Cotton surgical drape</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>two layers</td>
<td>8.3</td>
<td>0.78</td>
<td>0.17</td>
</tr>
<tr>
<td>four layers</td>
<td>6.5</td>
<td>0.99</td>
<td>0.38</td>
</tr>
<tr>
<td>Allegiance</td>
<td>7.8</td>
<td>0.83</td>
<td>0.22</td>
</tr>
<tr>
<td>3M Steri-Drape</td>
<td>7.8</td>
<td>0.83</td>
<td>0.22</td>
</tr>
<tr>
<td>Metallized plastic sheet</td>
<td>4.9</td>
<td>1.32</td>
<td>0.71</td>
</tr>
<tr>
<td>Thermadrape</td>
<td>5.5</td>
<td>1.17</td>
<td>0.56</td>
</tr>
<tr>
<td>Barkey thermcare I</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>one layer</td>
<td>6.1</td>
<td>1.06</td>
<td>0.45</td>
</tr>
<tr>
<td>two layers</td>
<td>4.8</td>
<td>1.34</td>
<td>0.73</td>
</tr>
<tr>
<td>Hospital duvet</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>one layer</td>
<td>3.4</td>
<td>1.90</td>
<td>1.29</td>
</tr>
<tr>
<td>two layers</td>
<td>1.9</td>
<td>3.40</td>
<td>2.79</td>
</tr>
</tbody>
</table>

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The correct determination of insulation values for different insulating materials is complicated by the fact that, while the air trapped within a mass insulator determines that insulator’s characteristics, the variable amount of air trapped beneath the insulator will increase its apparent insulation effectiveness. For this reason we excluded any obvious trapped air between the insulating material and the trunk of the manikin by smoothing flat all the test materials. In clinical practice there will be more trapped air under the insulation material and therefore the practical insulation of the materials will be slightly higher.

Insulation values of the insulation materials

The insulation value of air was 0.61 Clo, which means that air is a better insulator than the materials found in an operating room. A value of 0.61 Clo compares well with insulation values of air given by Burton and Edholm. The insulation materials had insulation values between 0.17 Clo and 2.79 Clo. This result is different from the results of a study by Sessler and colleagues, who concluded that there were only minor important differences among the thermal barriers. The reason for this is that we included effective insulating materials that are not commonly used in the operating room (e.g. hospital duvet). However, if we compare similar materials in both studies we find very similar results. We have also found that disposable covers are more effective than a cloth surgical drape, but they are less effective than a reflective material (e.g. Thermadrape). Adding additional layers of the insulating material increases the efficacy. This result is also comparable to a volunteer study. However, the exact influence of more layers on the reduction of heat loss is still to be determined.

In contrast to many clinical studies, the results of the radiant insulators were better than many other insulating materials. Possibly the efficacy of these materials is lowered in clinical practice by placing additional sterile drapes on them. This consideration is confirmed by studies that have found no improvement of thermal insulation by adding radiant insulators sandwiched into insulating materials. However, this problem requires further detailed analysis.

Conclusion

There are relevant differences between various insulating materials. Heat loss can be reduced in a relevant way by insulation materials, which should be applied to those areas of the body surface that cannot be warmed actively. The best commercially available material designed for use in the operating room (Barkey thermcare 1) reduces heat loss from the covered area by about 45% when used in two layers. However, with better insulating materials (e.g. two layers of a hospital duvet) heat loss can be reduced to about 80%. It should be possible to manufacture specially designed insulating materials for the operating room with insulation values of 2–2.5 Clo, as materials like this are used for...
outdoor activities\textsuperscript{18} and army uniforms.\textsuperscript{17} The effects of multiple layers of insulation and the effects of radiant insulators require further investigation.

Acknowledgement

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